INTEGRATED ASSESSMENT SYSTEMS
FOR CHEMICAL WARFARE MATERIEL

Kenneth D. Watts, Alan M. Snyder, Donald A. Verrill,
Robert J. McMorland, Gary L. Thinnes
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415-3840
Phone: 208-526-9628
Fax: 208-526-2061
E-mail: kdw@inel.gov

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Abstract

The U.S. Army must respond to a variety of situations involving suspect discovered, recovered, stored, and buried chemical warfare materiel (CWM). In some cases, the identity of the fill materiel and the status of the fuzing and firing train cannot be visually determined due to aging of the container, or because the item is contained in an over-pack. In these cases, non-intrusive assessments are required to provide information to allow safe handling, storage, and disposal of the materiel. This paper will provide an overview of the integrated mobile and facility-based CWM assessment system prototypes that have been, and are being developed, at the Idaho National Engineering and Environmental Laboratory (INEEL) for the U. S. Army Non-Stockpile Chemical Materiel Project. In addition, this paper will discuss advanced sensors being developed to enhance the capability of the existing and future assessment systems.

The Phase I Mobile Munitions Assessment System (MMAS) is currently being used by the Army's Technical Escort Unit (TEU) at Dugway Proving Ground, Utah. This system includes equipment for non-intrusively identifying the munitions fill materiel and for assessing the condition and stability of the fuzes, firing trains, and other potential safety hazards. The system provides a self-contained, integrated command post including an on-board computer system, communications equipment, video and photographic equipment, weather monitoring equipment, and miscellaneous safety-related equipment. The Phase II MMAS is currently being tested and qualified for use by the INEEL and the U. S. Army. The Phase II system contains several new assessment systems that significantly enhance the ability to assess CWM. A facility- based munitions assessment system prototype is being developed for the assessment of CWM stored in igloos at Pine Bluff Arsenal, Arkansas. This system is currently in the design and fabrication stages.

Numerous CWM advanced sensors are being developed and tested, and pending successful test results, may be incorporated in the various munitions assessment systems in the future. These systems are intended to enhance CWM fill materiel identification, agent air monitoring, agent or agent degradation product detection by surface analysis, and real-time x-ray capabilities.

Background

The United States ratified the Chemical Weapons Convention (CWC) treaty in April 1997. This treaty requires the U.S. and other countries to destroy their chemical warfare material (CWM) by April 2007. The U.S. has two basic types of CWM; these are stockpile and non-stockpile. Non-stockpile CWM is divided into five categories of materiel or facilities as such: binary chemical weapons, former production facilities, recovered CWM, buried CWM (when recovered), and miscellaneous items. In many cases, recovered and buried CWM cannot be identified by the standard munition markings, because these markings have deteriorated with time. In these cases, non-destructive assessment techniques are used to identify the contents of the munitions or containers. This is a much safer and less costly approach than drilling and sampling the items. The identity of the fill materiel must be known, so that the CWM can be properly stored and preparations can be made to destroy it.

The U.S. Army must determine if the CWM can be handled safely; therefore, it is very important to establish the status of the munition's fuzing and firing train during the assessment process. This is done non-intrusively using x-ray systems. The x-ray images also provide valuable information on the munition's fill level, and whether the fill materiel is liquid or solid. Many other non-intrusive techniques are employed to provide additional information about the status and identity of the item being assessed.

The U.S. Army Project Manager for Non-Stockpile Chemical Materiel (PMNSCM) began the development of integrated munitions assessment systems in 1995. These systems are both mobile and facility-based. The first munitions assessment system, MMAS Phase I System 1 (Figure 1), was completed and deployed in 1997, and the second, MMAS Phase II System 1 (Figure 2), will enter service in 1999.

Figure 1. Phase I System 1

Figure 2. Phase II System 1

Other munitions assessment systems are planned to enter service in 2000 and 2001. The operational plans for the various integrated systems are described below. The capability of each system is also described along with a discussion of the effort to develop the next generation of sensors for the munitions assessment systems.

MMAS Operations

The NSCM project requires rapid response to a variety of situations involving discovered or recovered CWM. In conjunction with this rapid deployment capability, a system is needed that includes unique hardware capabilities to identify and assess various hazardous materiel items. The MMAS provides a mobile platform for systems and equipment to identify and assess CWM. For example, Portable Isotopic Neutron Spectroscopy (PINS) (Figure 3) is used for the non-intrusive characterization of elemental components in the chemical fill of munitions.

Identification of specific elements can assist in determining the type of agent present, if any, and possibly indicate the degree of agent degradation. Additional assessments of the CWM can be performed using field-portable radiography systems (Figure 4) and various chemical agent monitoring devices.

Figure 3. PINS assessing SRC

Figure 4. Andrex assessing SRC

Phase I System 1 Operations

For the most part, the MMAS Phase I System 1 (Figure 5) will be used as an initial response system for unplanned field operations to assess recovered munitions.

Figure 5. Phase I System 1 deployed at Dugway Proving Ground, UT.

These operations will deal with a range of munitions, including those recovered at test and training ranges. MMAS Phase I System 1 may also be used to support limited, planned reassessment activities of recovered munitions stored in igloos. Many of the NSCM munitions currently stored in igloos are categorized as having "unknown fill." The MMAS Phase I system will identify the munition type; identify the chemical fill; evaluate the condition of the CWM; determine if fuzes, bursters, or safety and arming devices are in place; and provide other data necessary for assessing risks associated with handling, transporting, and disposing of CWMs.

The “assessments” will provide decision makers [e.g., the Explosive Ordnance Disposal (EOD) team leader, the PMNSCM, and the Munitions Assessment Review Board (MARB)] with complete, accurate, and consistent assessment information to allow them to make safe and prudent decisions relative to handling, transporting, storing, disposing, and/or reporting items that are suspect or known CWM. The MMAS Phase I System 1 provides the Army with the capability to meet the immediate need to augment response equipment currently used by the Technical Escort Unit (TEU).

To fulfill its operational goals, the MMAS Phase I systems consist of a commercial, four-wheel drive pickup truck towing a gooseneck trailer. The trailer is loaded with an interactive network of non-intrusive characterization and assessment NDE systems including the following:

1) Portable Isotopic Neutron Spectroscopy (PINS), a nondestructive analysis technique which detects characteristic gamma rays from nuclei activated by neutrons. The PINS system will be used to identify the elements within a munition, thereby disclosing the contents without drilling the casing or handling the chemicals inside.
2) Two field portable radiography (i.e., X-ray) systems that can provide detailed images of the munition. The radiograph imaging system used with the radiography systems will be film-based (requiring X-ray film developing) or radioscopy using a video display monitor (i.e., CRT).
3) Gross-level air monitoring systems using ion mobility spectroscopy (IMS), a technique that generates a spectrum of fragment ions based on ion migration time. This migration time of the fragment ions is a function of their mass, size, and shape. Ion spectra of complex compounds contain one or more characteristic peaks that can be used for class or compound-specific agent monitoring.

Phase I System 2 Operations

The MMAS Phase I System 2 (Figure 6) will be very similar in design to the Phase I System 1 and will perform the same operational functions. The design is somewhat less complex than System 1. This system is expected to be deployed in 2000 at Pine Bluff Arsenal, Arkansas.

Figure 6.
Phase I System 2

Phase II System 1 Operations

The MMAS Phase II system (Figures 7 and 8) will be used primarily for planned characterization operations involving NSCM munitions stored in separate facilities at Chemical Stockpile Disposal Program (CSDP) installations and to characterize items at recovered ordnance and remediation sites.

Figure 7. Phase II Communications (curbside)

Figure 8. Phase II Storage Drawers (roadside)

The MMAS Phase II system provides a broader assessment capability than the MMAS Phase I system; hence, more time will be required to perform the assessment. The MMAS Phase II system may assist in the identification of unexploded ordnance (UXO) prior to on-site treatment or prior to shipment off-site for treatment at a special treatment, storage, and disposal facility. Like the MMAS Phase I system, the MMAS Phase II system can also be used as an "initial response system" for unplanned, field operations. The MMAS Phase II system (with its enhanced capabilities) may also be deployed to a site as a follow-up to the initial response by MMAS Phase I system.

Like the MMAS Phase I system, the MMAS Phase II system will be used to identify the munition type; identify the chemical fill; evaluate the condition of the CWM; determine if fuzes, bursters, or safety and arming devices are in place; provide other data necessary for assessing the risk associated with handling, transporting, and disposing of CWM; and record the data on a dedicated computer system. In addition, the MMAS Phase II system will evaluate the environmental conditions in the vicinity of the CWM.

The MMAS Phase II system consists of a motor home to transport the following non-destructive evaluation (NDE) systems which are also included with the MMAS Phase I systems:

1) PINS system,

2) Two field portable radiography systems, and
3) Gross-level air monitoring systems (i.e., M-90s, [Figure 9]).

Figure 9.
M-90

The MMAS Phase II system will also include the following state-of-the-art NDE systems to further assess the environmental conditions in the vicinity of the CWM and the suspect munitions themselves:

1) Secondary Ion Mass Spectrometry (SIMS) (Figure 10), a surface analytical technique used for obtaining chemical fingerprints of surfaces. An ion trap SIMS system will be used to detect the presence of chemical agent or non-volatiles on the munition surface or in the surrounding area (e.g., soil and over pack). All elements, including hydrogen, are detectable at parts per million (ppm) levels (or lower) by SIMS. The method involves bombarding a solid sample with an energetic ion beam and monitoring sample atoms (i.e. secondary ions) that are ejected and analyzed via a mass spectrometer.

Figure 10.
SIMS

SIMS is extremely attractive for assessing suspect CWM for the following reasons:

- No sample preparation is required,
- No waste is generated,
- Analysis is rapid and simple,
- Capable of specification "fingerprinting,"
- Amenable to almost any sample type, and
- Amenable to non-volatile organics and salts.

2) Phase Determination System (Figure 11), a non-intrusive technique capable of detecting subtle changes in a container's vibration characteristics caused by differences in the physical properties of the fill material.

Figure 11. Phase Determination System

Typically, the density and viscosity of the fill material affect the frequencies at which vibration resonances occur and affect the amplitudes of those resonances. By collecting and displaying spectrums of the munition during the excitation and non-excitation periods, a determination can be made whether the munition is empty or filled with a liquid or a solid.

2) Advanced radiography systems, including:

Figure 12. Gamma Densitometer

•Gamma Densitometry (Figure 12), a method using the measurement of the attenuation of X-rays or gamma rays through an object to estimate the material density or X-ray linear attenuation coefficient of the object. Given a sufficient difference in the density or linear attenuation coefficient of each chemical fill material, the material may be uniquely identified.

•Digital Radiography and Computed Tomography (Figure 13), a technique measuring the attenuation of X-rays through an object to determine the physical structure of the object in both two-dimensional sections and three-dimensional volumes.

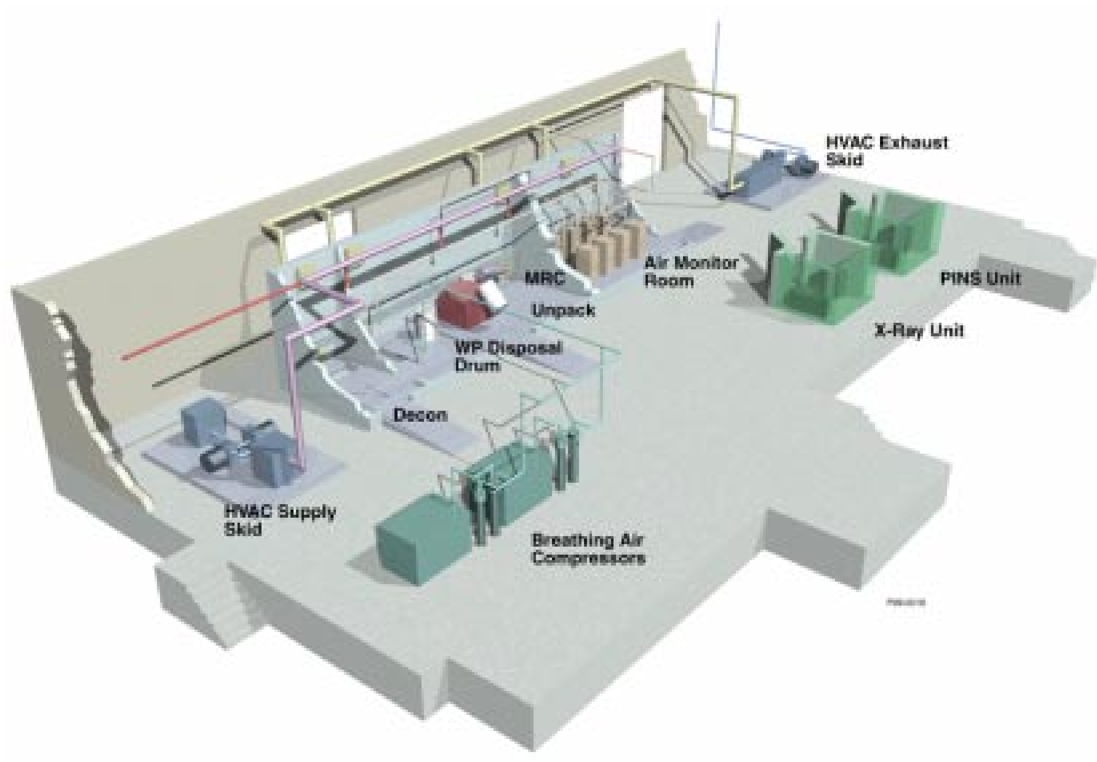
Figure 13.
DRCT System

The detailed images provided by a digital radiography and computed tomography system can provide significantly more information about the munition firing train (i.e., fuses, bursters, or safety and arming devices) and the overall condition of the munition than traditional radiography. In addition, digital radiographs and "real time" radiography allow for the selection of the optimum orientations and locations to make a gamma densitometry measurement. The gamma densitometry technique requires that several assumptions be made; 1) uniform cylinder walls, 2) homogeneity of material, and 3) void space availability. All of these problems may be overcome if the spatial distribution of material and casing are well defined.

3) Low-level air monitoring systems, using either gas chromatography (GC), a well established technique for separating mixtures of vapor-phase chemicals, or enhanced IMS systems, which are currently being tested at Aberdeen Proving Grounds, Maryland. GC systems typically consist of a sampling device, separation column, and detection device. Various detection systems can be used to identify chemicals, including flame photometric, flame ionization, electron capture, nitrogen-phosphorus, mass spectrometric detectors, and photoionization. These detectors can identify chemical agents with varying degrees of specificity and sensitivity. The enhanced IMS systems are much more sensitive than the systems being used on the MMAS Phase I and they would require no chemical agent standards for calibration.

Pine Bluff Arsenal Munitions Assessment System Operations

The Pine Bluff Arsenal Munitions Assessment System (PBA MAS) (Figure 14) will be a skid-mounted, facility-based system, that contains an interactive network of non-intrusive munition and container assessment equipment.



This equipment includes: advanced radiography (x-ray) systems, Portable Isotopic Neutron Spectroscopy (PINS) systems, chemical agent detection equipment, a data acquisition and handling system, video equipment, communications equipment, and various support equipment. Provisions are also included for performing decontamination and CWM repackaging. The data developed by the PBA MAS will be used by the U.S. Army's Munitions Assessment Review Board (MARB) to make recommendations regarding how a munition should be categorized. For chemical munitions, the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM) will determine the appropriate methods and safeguards necessary to transport, store, and dispose of the agent-filled munitions in a timely, safe, and environmentally acceptable manner.

The Pine Bluff Chemical Activity (PBCA) recovered CWM inventory is currently stored in seven NSCM designated igloos. Single or multiple drums, boxes, or pigs, each containing single or multiple munitions, are stored on wooden pallets. Munitions assessment and repackaging will be conducted in a MAS located at a site which has yet to be determined.

The major munitions processing steps performed inside the PBA MAS are shown on Figure 15. The munition containers will be x-rayed inside their respective igloos to determine:

- The number, type, and orientation of the munitions in each munitions container;
- Whether any additional containers are present (e.g. a 35 gallon drum inside of an 85 gallon drum);
- Whether any discernible amount of liquid is present in the bottom of the container;
- Whether any significantly damaged items are present;

- Liquid levels in the munitions;
- Whenever possible, the presence and conditions of fuzes and bursters.

After the digital radiography and computed tomography is completed in the igloo, the container will be transferred to the PBA MAS, and the following steps will be completed:

- A single drum will be brought into the PBA MAS unpack/repackage room;
- The container will be opened, monitored for munitions' leakage, and the munitions will be removed;
- Munitions will be visually examined and photographed, leaks will be sealed, and decontamination will be performed when necessary;
- Each munition will be uniquely identified, labeled, and individually repackaged in a Single Round Container (SRC) or Multiple Round Container (MRC).
- Each SRC or MRC will be checked for external contamination and decontaminated if necessary.

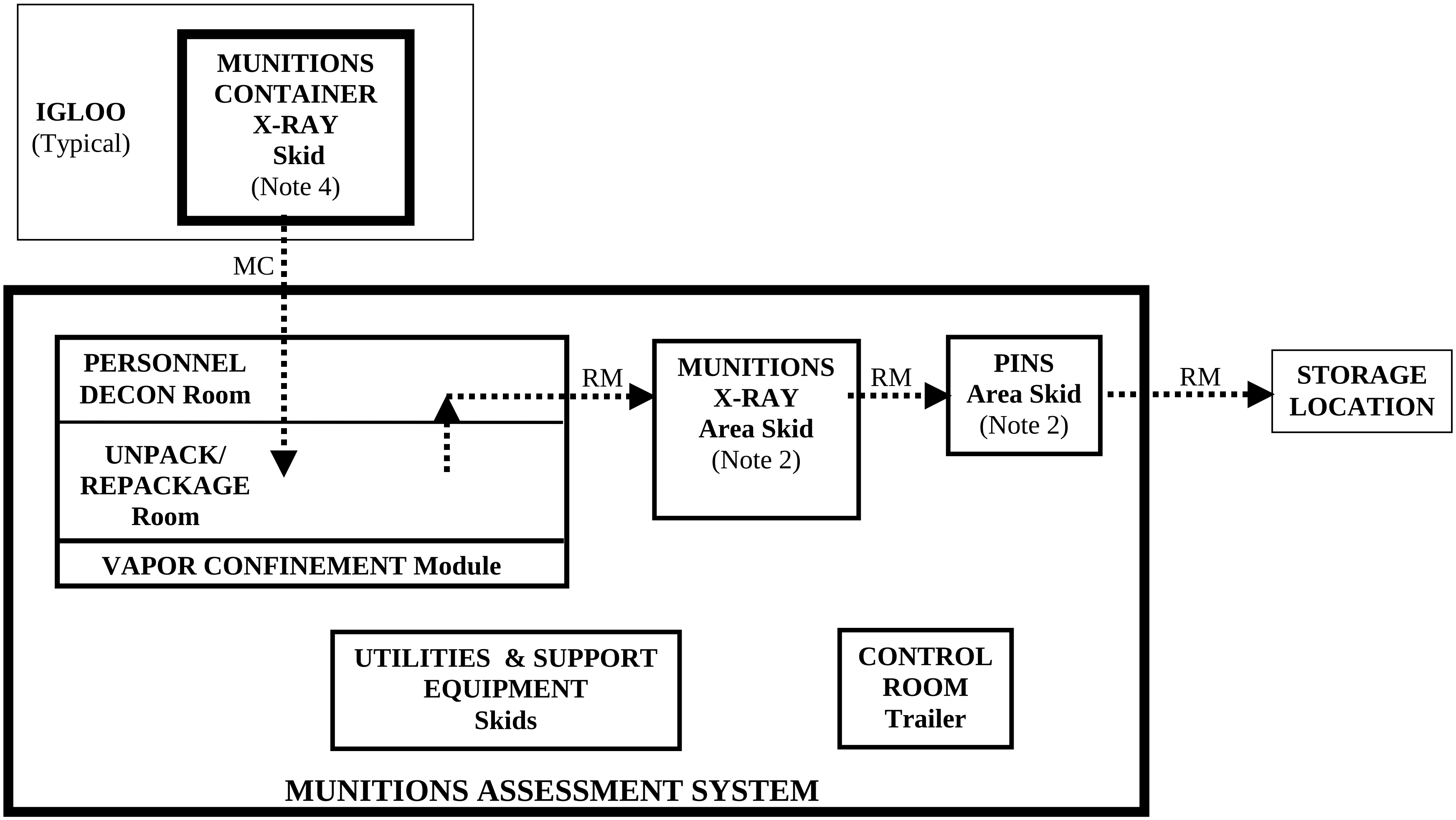


Figure 15. PBA Processing Steps

The SRC or MRC will then be removed from the PBA MMAS module and transferred to the munitions x-ray system, where it will be x-rayed to determine the status of the munition's firing train and to detect the presence and level of liquid fill inside the munition. Next, the munition will be examined using PINS to identify the presence of key elements, which will provide an indication of the type of chemical inside the munition. Finally, an assessment data package will be compiled and attached to the SRC or MRC, which will be transported to an interim holding facility or designated igloo in preparation for destruction.

Advanced Sensors Project

The goal of the MMAS Advanced Sensors Project (MMAS-ASP) is to develop field deployable assessment systems that will enhance the capabilities, not only of the MMAS Project's Phase I & II development, but also the capabilities of the other PMNSCM assessment projects. This development ranges from integration of the latest, marketed technologies for near-term application to MMAS operations to research of new ideas to be evaluated, proven, and developed for integration into the MMAS Phase II and facility-based characterization systems. The following Advanced Sensors Projects are described below:

- Field Ion Spectrometry
- Wide Area Monitoring
- Portable Raman Spectroscopy
- Facility-Based PINS
- Swept Frequency Acoustic Interferometer
- Light Weight Chemical Detector

Field Ion Spectrometry (Figure 16)

The ability to detect and identify very small amounts of chemical warfare (CW) agent vapors during chemical demilitarization activities is a very important capability. If CW agents can be detected and identified in real time at extremely low levels, the safety envelope of the demilitarization activities is greatly enhanced.

Figure 16. Field Ion Spectrometry System

Devices of this nature, designed as portable detectors for battlefield use are based upon ion mobility spectrometry (IMS); a gas phase, atmospheric pressure, ionization technique where analyte ions are separated by their velocities in an electric field at ambient pressure. The IMS instrument offers very high sensitivity to CW agents, with the ability to identify different agents, all in real time.

In the late 1970s, a new type of Ion Mobility Spectrometry (IMS) instrument was being developed in Russia. This new spectrometer utilized the field-dependent nature of ion mobility to better control and enhance separation parameters among various analytes. This new instrument design, called Field Ion Spectrometry (FIS), does not have an ion gate, and thus has the potential for much greater sensitivity than conventional IMS. This new technology was licensed and further developed in the U.S. by Mine Safety Appliances Company. The unit has been thoroughly tested by MSA on CW agent simulants with impressive results. The data have shown detectability of the simulant DMMP at 400 parts per trillion (ppt) and DPM at 179 ppt. The strong signal-to-noise ratio at these quantities suggests that the detection limit is much lower.

This Advance Sensors Project consists of an evaluation of FIS for development as a portable sensor that would communicate with the MMAS platform, implementation into the platform data collection system, and field testing. Little to no fundamental research needs to be done with the FIS system on CW agents, as the data from the U.S. Army Edgewood Research, Development & Engineering Center and JCAD evaluations can be utilized to provide most needed information about the detection system's performance. The project is focusing on the evaluation and configuration of the detector and the value of the data it provides with respect to the entire MMAS mission.

Wide Area Monitoring (Figure 17)

Figure 17. Wide Area Monitoring Setup

The MMAS has a need for air monitoring instrumentation to ensure that harmful chemicals are not being released into the working environment or outside the assessment site. The Chemical Agent Monitoring (CAM) instruments currently in use are capable of monitoring for chemicals only at the point where air is drawn into the instrument. With these CAMs, the safety of the workers and the public is ensured by using a large number of instruments placed at various locations around the site.

An improved approach is to design a wide-area monitor, based upon optical techniques, that could provide real-time measurements integrated across the assessment site. This project uses the superior noise performance of laser diode devices in the design of an ultra-sensitive absorption spectrometer for the broad area measurement of hazardous agents found at chemical munitions sites. This project involves the design, fabrication, and field testing of an optical system to perform broad area monitoring of chemical agent leaks during a munition assessment.

Laboratory testing has indicated that the vapor of the surrogate, DMMP, can be detected in a 100-meter path at levels commensurate with the workplace exposure limits of non-stockpile chemical agents. At this point, the system still has some noise problems that are being corrected and will reduce detection limits even further.

Portable Raman Spectroscopy (Figure 18)

Between 1920 and 1960, more than 110,000 Chemical Agent Identification Sets (CAIS) were produced to train personnel in the identification of chemical agents. These chemical agents and industrial chemicals were stored in glass ampules and bottles. These ampules and bottles were packaged in boxes or metal shipping containers. Many of the sets were expended during training; however, unused CAIS were buried in landfills and stored in igloos. It is expected that both complete and partial CAIS, consisting of loose bottles and ampules, will be discovered and recovered.

Figure 18. Raman Spectroscopy System

Raman spectroscopy is a proven technique for characterization of such chemicals in glass containers; however, current systems in use are large and not portable.

This project is integrating an existing, off-the-shelf Raman Spectrometer into a package that weighs less than 100 pounds and operates on standard 120 VAC power. The unit is designed for portability, user-friendliness, and easy deployment away from the MMAS vehicle.

Facility-Based PINS

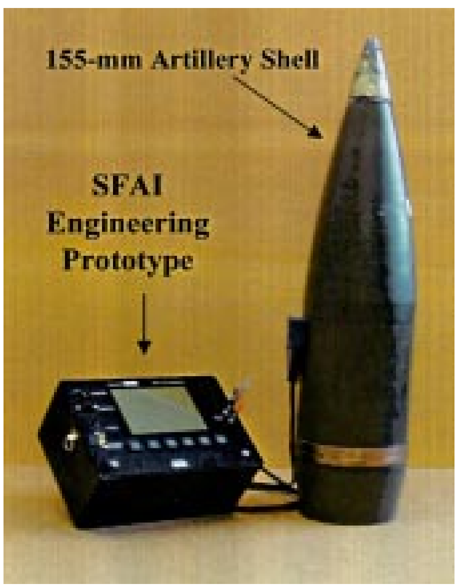
Large munition assessment projects will severely tax present MMAS assessment systems, including the PINS system. To handle a large volume of munitions in a few months time will require improved throughput for the PINS system. The PINS system faces a challenge of the wide variety of chemical fills expected at large storage sites. Some of the non-stockpile munitions are known to date back to World War I. To keep PINS reasonably portable for MMAS needs, design compromises were necessary to minimize system weight and power consumption. For fixed installations, such as storage facilities, weight and power are not important concerns so throughput rates can take a higher priority in the design.

The following factors presently limit PINS throughput:

- Neutron source energy and intensity
- Detector shielding
- Electronic counting-rate limitations
- Spectrum analysis software

This project addresses each of the factors listed above to optimize the PINS system for fixed installation assessments.

Swept Frequency Acoustic Interferometer (Figure 19)



The Defense Threat Reduction Agency (DTRA), which includes the agency formerly known as the Defense Special Weapons Agency, and its contractor, Los Alamos National Laboratory, are currently in the final stages of developing a small, portable system for characterizing the liquid contents of a munition or other container non-intrusively. The original intended use of the system was to help verify compliance with the Chemical Weapons Convention Treaty.

Figure 19.
SFAI Prototype

The underlying principal for facilitating characterization of the liquid is based upon the electro-mechanical excitation of the shell or container and measuring the acoustic response of the liquid in the container. A swept frequency vibration of a piezo-electric transducer is used to establish acoustic resonances in the medium within the shell cavity. A second piezo-electric transducer measures the vibration response at the shell surface. Characteristics of the contained material such as density, speed of sound, and frequency-dependent sound attenuation can be determined from the measured swept frequency spectrum of resonant peaks. These parameters are used to characterize the material within.

This project is evaluating the SFAI system for application to the MMAS mission. Should the system prove to be adaptable to MMAS, any needed modifications will be planned, developed, and demonstrated prior to integration into the MMAS platform.

Lightweight Chemical Detector (Figure 20)

MMAS assessments need the support of a wide range of chemical agent vapor detectors. The Wide-Area Monitor is being developed to monitor across the assessment sight. The FIS is being developed as a very sensitive, local area vapor detector with a sampling wand. ERDEC has tested a bread-board version of a hand-held ion mobility spectrometer, the Lightweight Chemical Detector (LCD) developed by Graseby, that has good sensitivity to multiple agents.

Figure 20.
Graseby LWCD

Currently, the LCD can detect nerve agents at concentrations in the 0.1 mg/m^3 range and blister agents in the 1 mg/m^3 range. With the integration of a pre-concentrator to this unit, a hand-held, or belt-mounted chemical agent detector could provide assessment workers near real-time detection. It is expected that this detector with pre-concentration could reach sensitivity levels to agent concentrations one to two orders of magnitude lower.

Pre-concentration of a specific agent will occur “off-line” while the multiple agent monitoring continues. This pre-concentration would take about five minutes. Then, when the pre-concentrated sample is ready, the instrument is cleared, and the analysis of the sample is made within a few seconds. Subsequently, the instrument is cleared of the pre-concentrated vapor and multi-agent detection would begin again within a few seconds.

Conclusion

An impressive suite of equipment and systems has been, and is being, developed to assess discovered and recovered chemical warfare materiel. One mobile system is currently available, a second system will be in service in 1999, and a third mobile system is expected to be available in 2000. A facility-based CWM assessment system is currently being developed and should be available in 2001. This assessment system provides the additional ability to unpack drums containing chemical munitions and to provide for decontamination.

Advanced sensors are currently under development to further improve the ability to assess discovered and recovered CWM. These sensors will be added to the assessment systems as they become available.

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